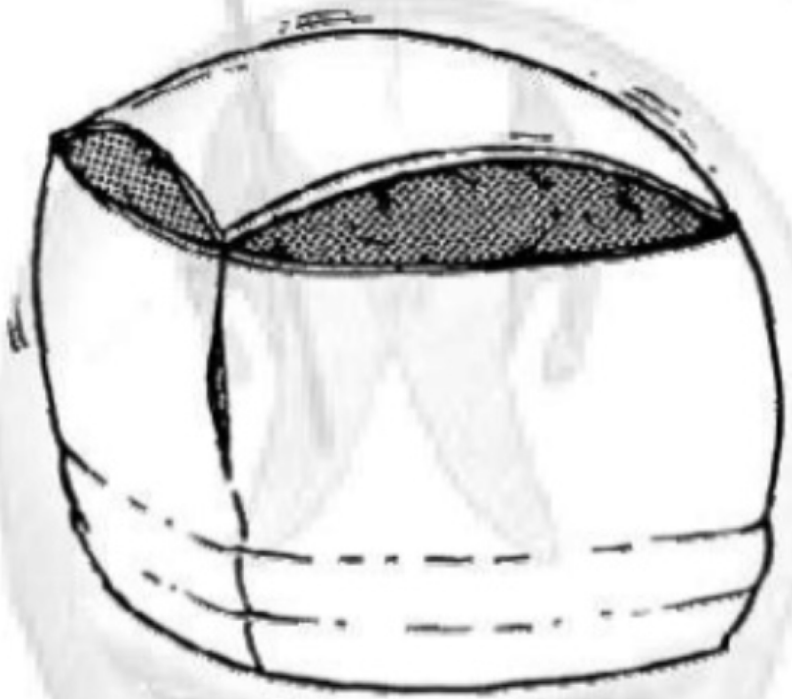
Intracranial Pressure Monitoring

Monro-Kellie doctrine



- skull
  - closed box, fixed volume
- contents
  - blood, brain and CSF
  - non-compressible fluids

increase in one component (brain swelling)

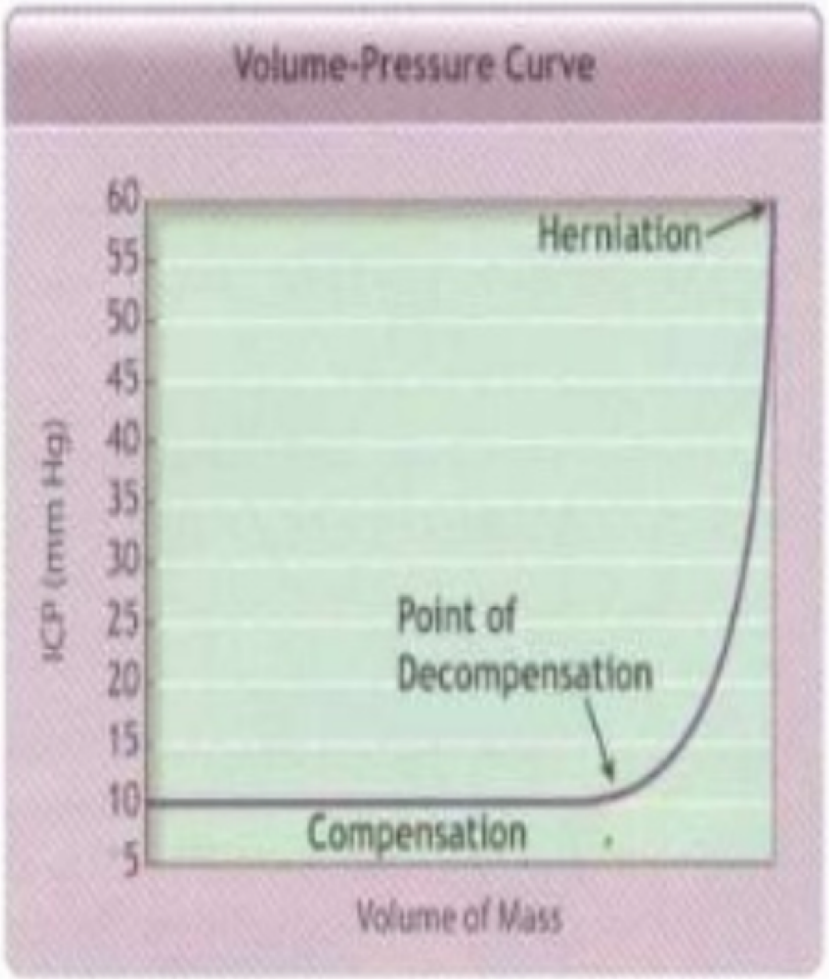
or

addition of new component (haematoma)

displaces another component

'compliance'

- “compliance reflects the ability of the intracranial system to compensate for increases in volume without subsequent increases in ICP. **When compliance is decreased, even small increases in intracranial volume result in large increases in ICP.**”



$$V_{intracranial\ vault} = V_{brain} + V_{blood} + V_{CSF}$$

- Harvey Cushing
  - With an intact skull, the sum of brain volume, CSF volume, and intracranial blood volume is constant
  - An increase in one component should cause a reduction in one or both of the other two

Why is ICP Monitoring Important

- Confirm or exclude intracranial hypertension
- Initiate ICP lowering measures as early as possible
- Determine whether intervention is effective
- Especially important in sedated or unresponsive patients

Indications for ICP Monitoring

- Head injury/TBI
  - GCS < 8
  - Posturing -- flexion/extension
- Subarachnoid hemorrhage
- Stroke
- Intracerebral hematoma
- Hydrocephalus
- Perioperatively: resection of large brain tumors or AVMs when concern for cerebral edema is high and clinical neuro exam is not possible

Dynamics of ICP

- Information that can be derived from ICP monitoring
  - CPP
  - Regulation of CBF and volume

ICP Waveforms

- P1 = Percussion Wave
  - arterial pulsation
- P2 = Tidal Wave
  - intracranial compliance
- P3 = Dicrotic Wave
  - venous pulsation

Normal ICP waveform		
Peak	**Wave**	**Origin**
First large peak	Percussion wave W_1 (pulsatile)	Systolic pressure, large intracranial arteries and choroid plexus CBF
Second small peak	Tidal wave W_2 (pulsatile)	Central venous wave from right atrium, from brain increased elastance/ decreased compliance
Inverted	Inverted	Miscalibrated monitor
Third small peak	Dicrotic wave W_3	Arterial pulse
Expiration	Increases overall wave	Increasing central venous pressure
Inspiration	Decreases overall wave	Decreasing central venous pressure

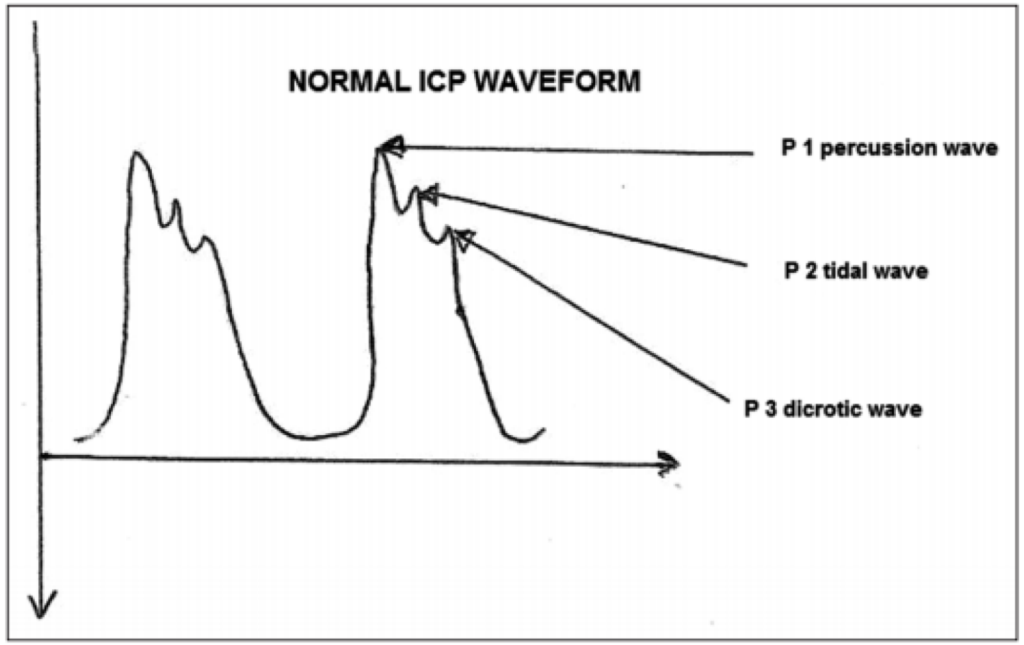
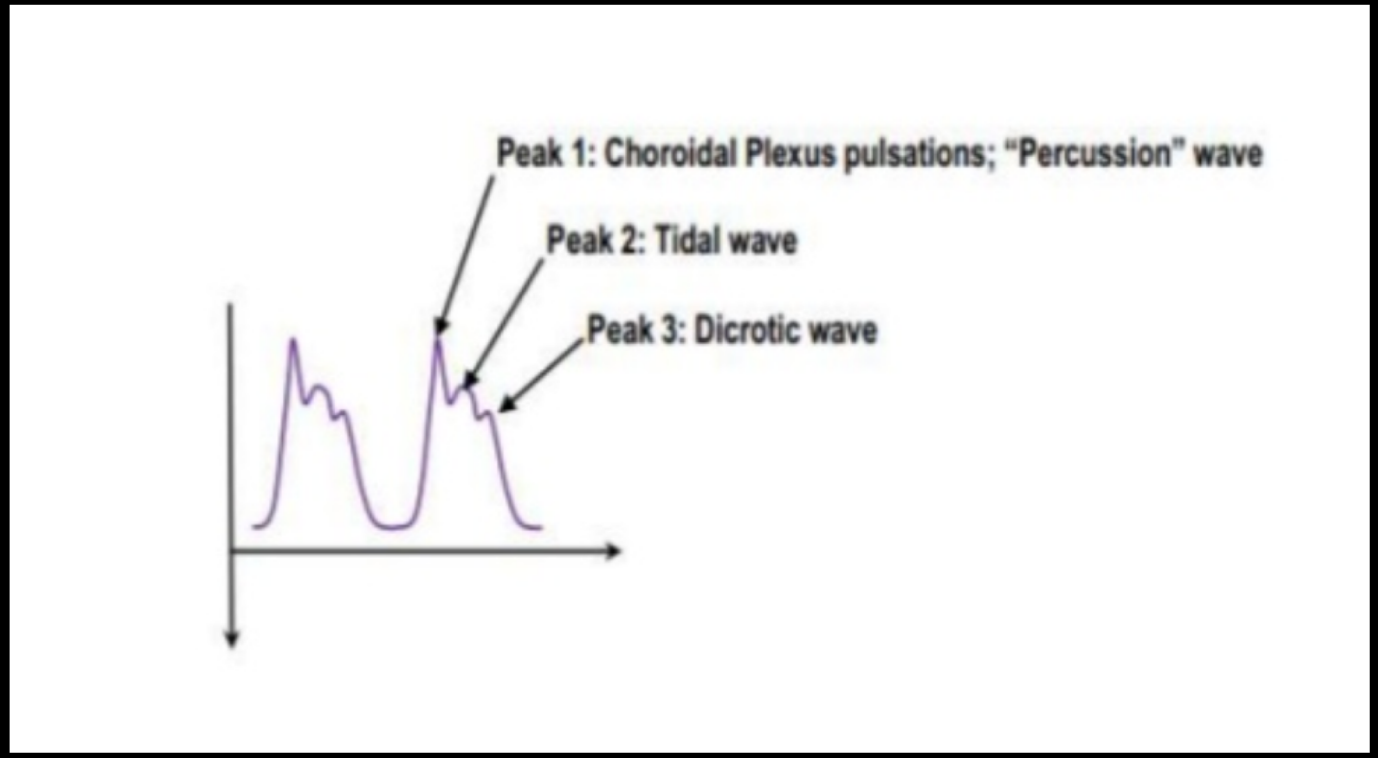
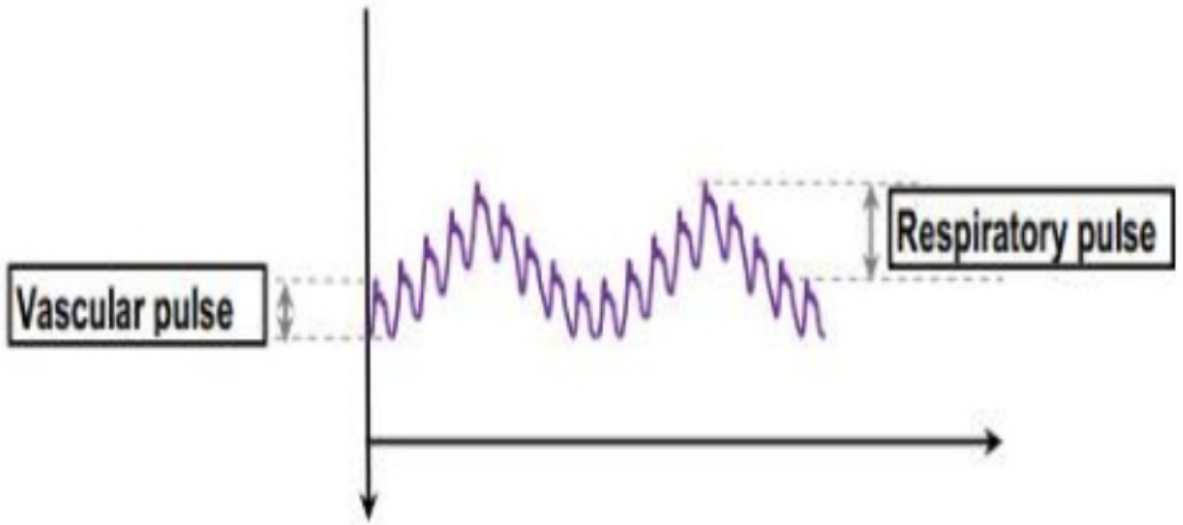


Figure 3: Intracranial pressure waveform reflecting three peaks – P1 (correlating with the arterial pulse); P2 (relating to the cerebral compliance); P3 (corresponding to aortic valve closure)



Related to

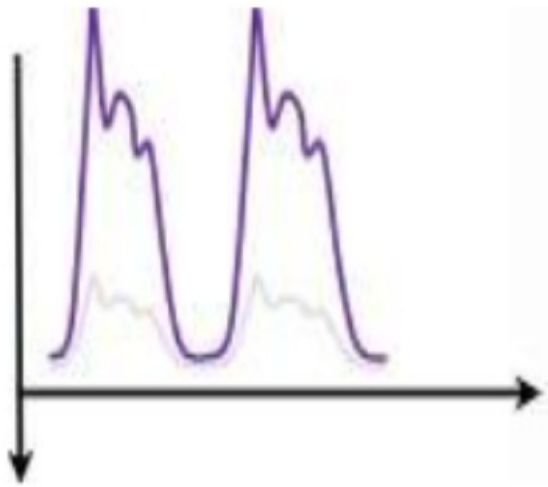
- Cardiac cycle : within individual waves
- Respiratory cycle : between consecutive waves



Flat

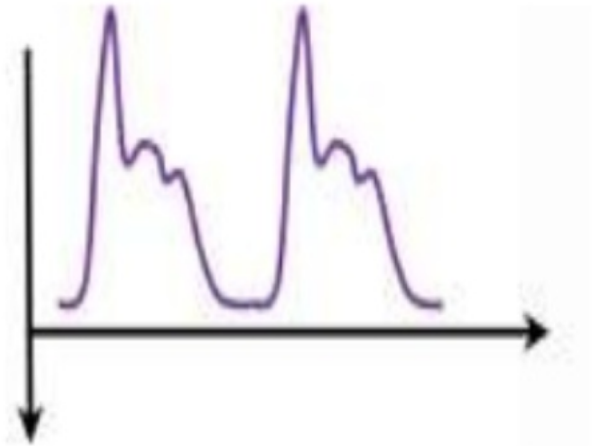
- EVD clogged / kinked
- Patient expired

↑/↓ amplitude



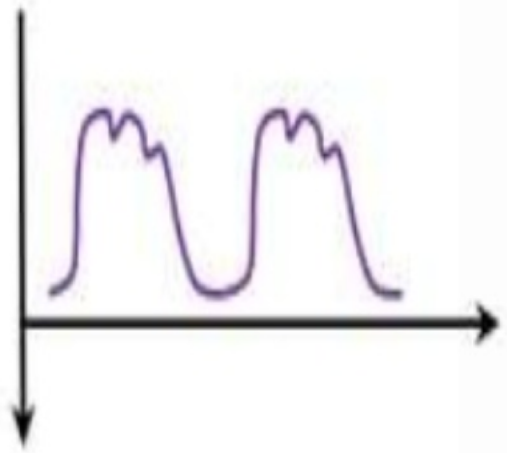
- Increasing CSF volume (or decreased)
- If a large volume of CSF is drained off, the waveform will decrease in amplitude.
- Missing bone flap

Prominent P1 wave



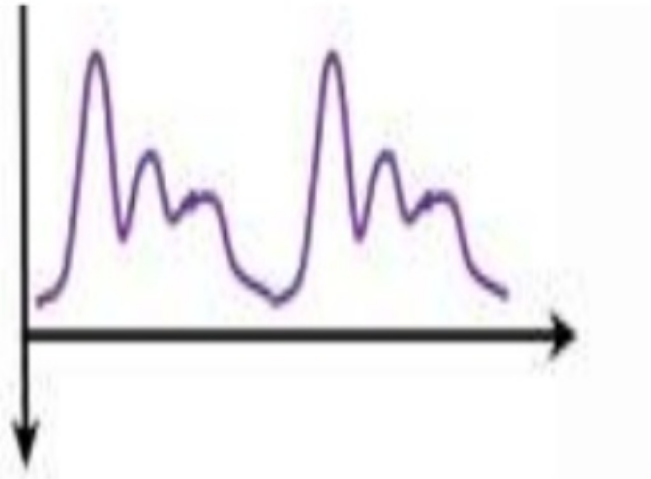
- The systolic BP is too high

Diminished P1 wave



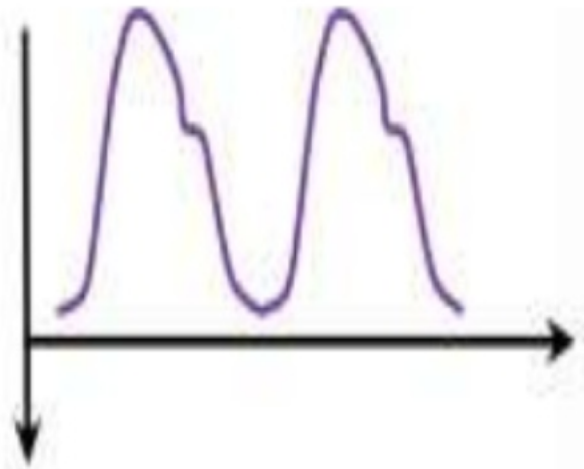
- If the systolic BP is too low, P1 decreases and eventually disappears, leaving only P2.
- P2 and P3 are not changed by this.

Diminished P2 and P3 waves



- Hyperventilation

Rounded ICP waveform



- ICP critically high

Nils Lundberg & his waves …

Lundberg A Waves

- ICP is increased and IC compliance is decreased, pathological waves appear
- Characteristic of conditions that lead to a reduced intracranial compliance (amplitude of 50-100 mm Hg); occur for 5-10 min
- Indicate low CPP and ischemia, ominous sign for herniation

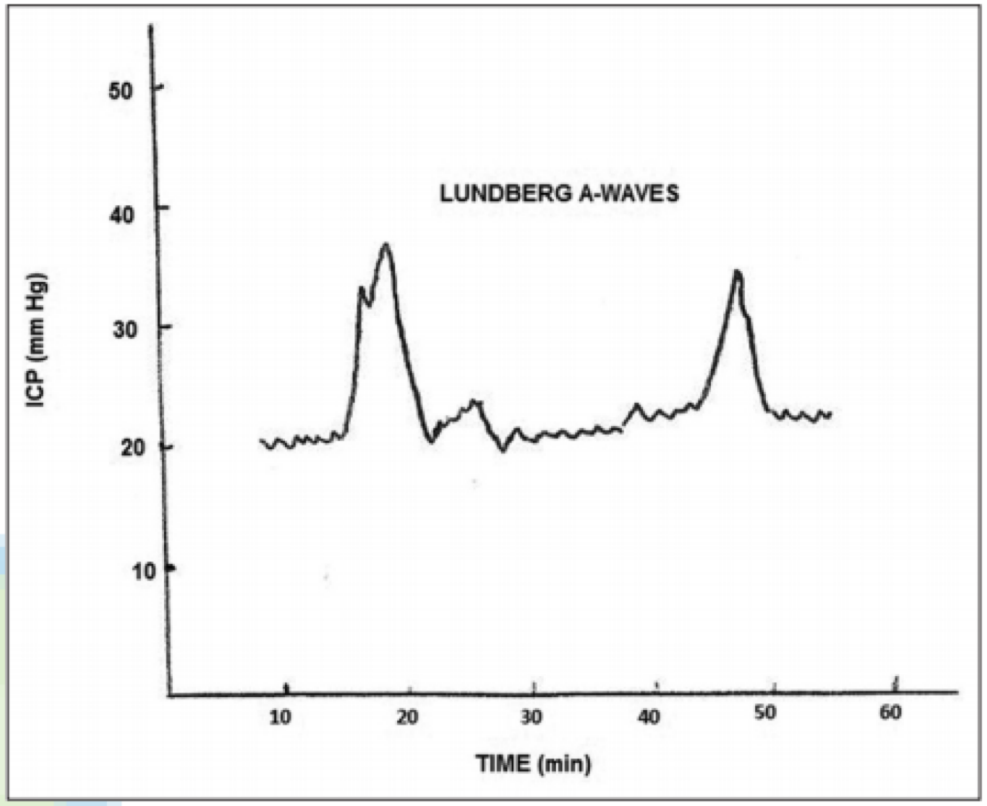


Figure 5: Schematic diagram depicting Lundberg A waves (intermittent sharp peaks)

Lundberg B waves

- Rhythmic oscillations, sharply peaked, occurring every 1-2 minutes; ICP increases in a crescendo manner to 20-30 mm Hg from a variable baseline, not sustained
- Reflect vasomotor changes, associated with unstable ICP

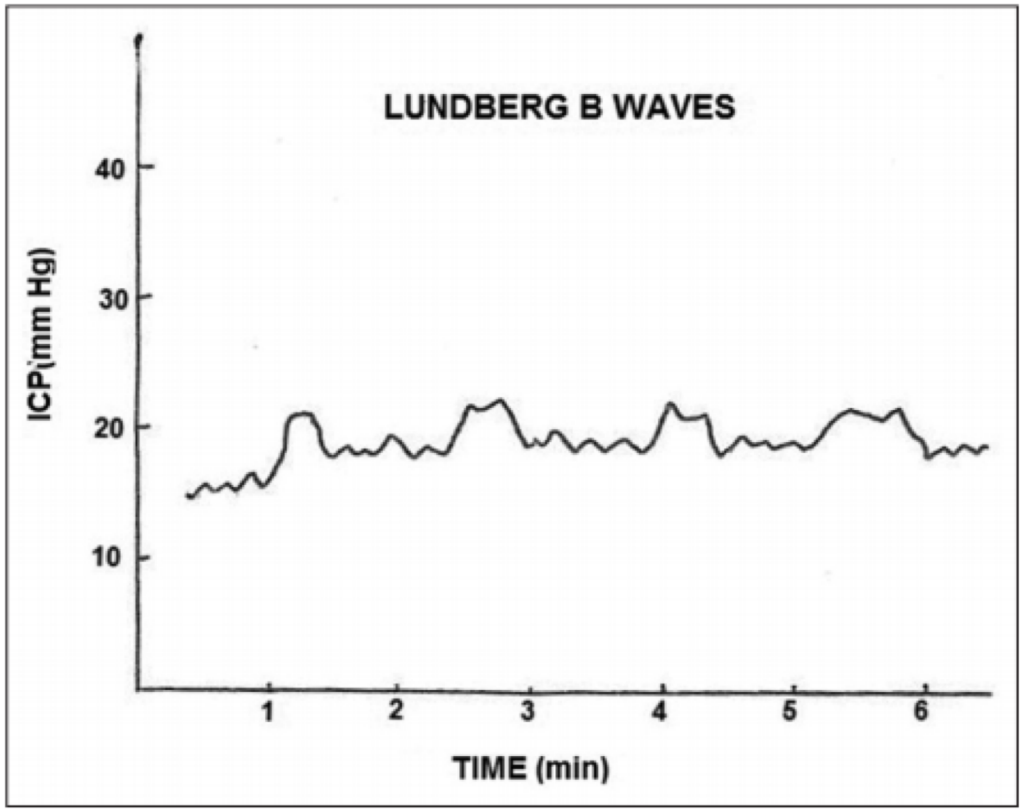
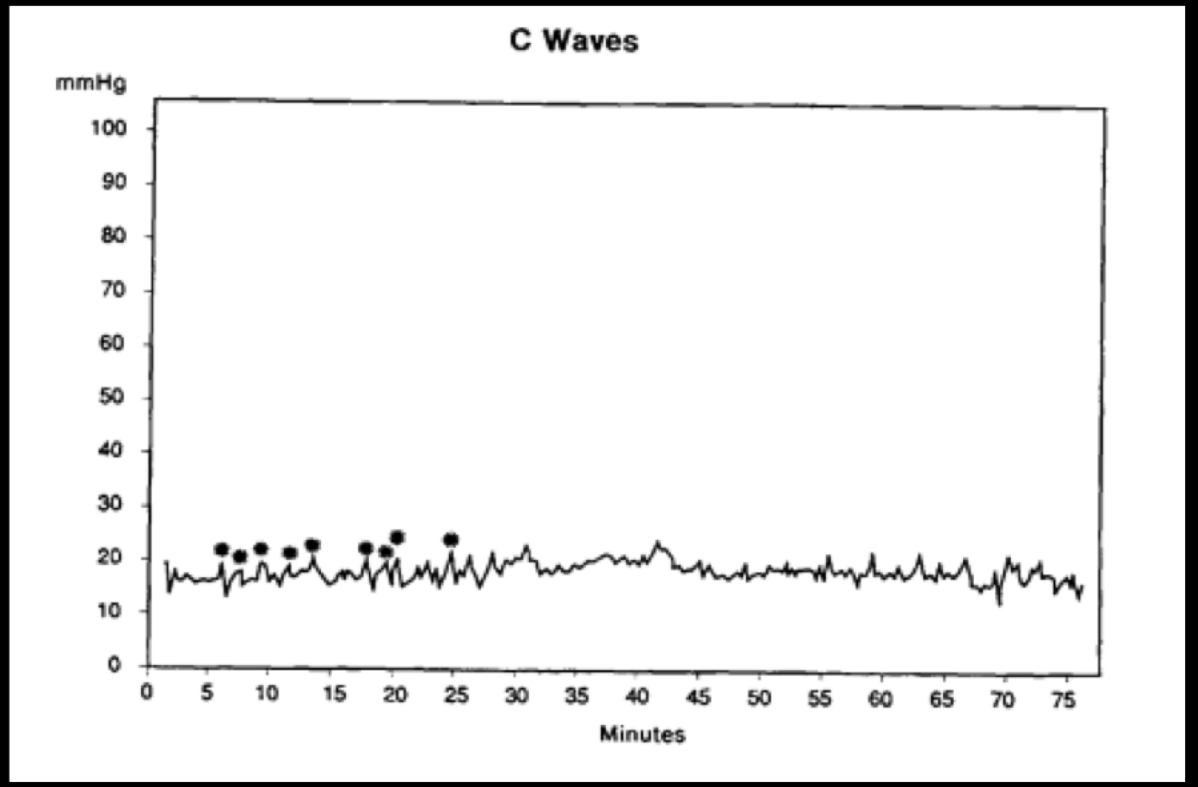


Figure 6: Schematic diagram showing Lundberg B waves

Lundberg C waves

- Correspond to Traube-Hering-Meyer fluctuations in arterial pressure brought by oscillations in baroreceptor and chemoreceptor reflex control systems
- Documented in healthy adults with no clinical significance



Methods of ICP Monitoring

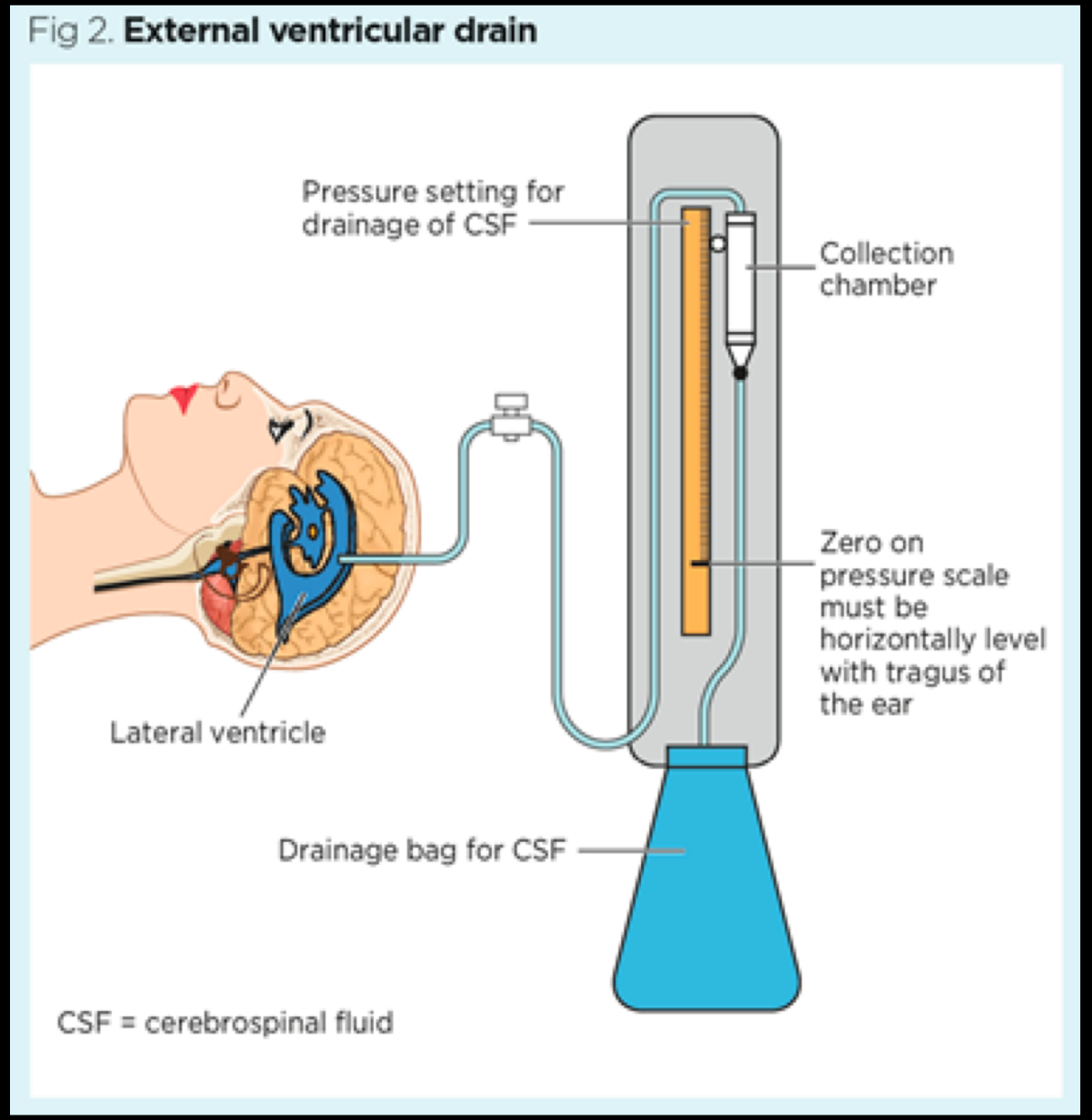
- Invasive (slides below)
- Non-invasive
  - Clinical exam
  - Non-contrast head CT
  - MRI
  - Transcranial Doppler Ultrasonography
  - Tympanic Membrane Displacement
  - Optic Nerve Sheath Diameter

Methods of ICP Measurement

- Location
  - Ventricular (EVD)
  - Intraparenchymal
  - Subarachnoid
  - Subdural/Extradural
  - External Fontanelle
- Technology
  - External strain gauge
  - Catheter tip
  - Strain gauge
  - Fiberoptic

EVD

- EVD connected to external strain gauge is gold standard
- Long history, low cost, reliable
- Therapeutic and diagnostic
- Success rate ~ 82%
- Malposition 4-20%
- Hemorrhage 0-15%



- Intraparenchymal devices
  - Fiberoptic devices, e.g., the Camino ICP monitor, the Innerspace ICP monitor
  - Strain gauge devices, e.g., the Codman MicroSensor, the Raumedic Neurovent P ICP sensor, and the Pressio sensor

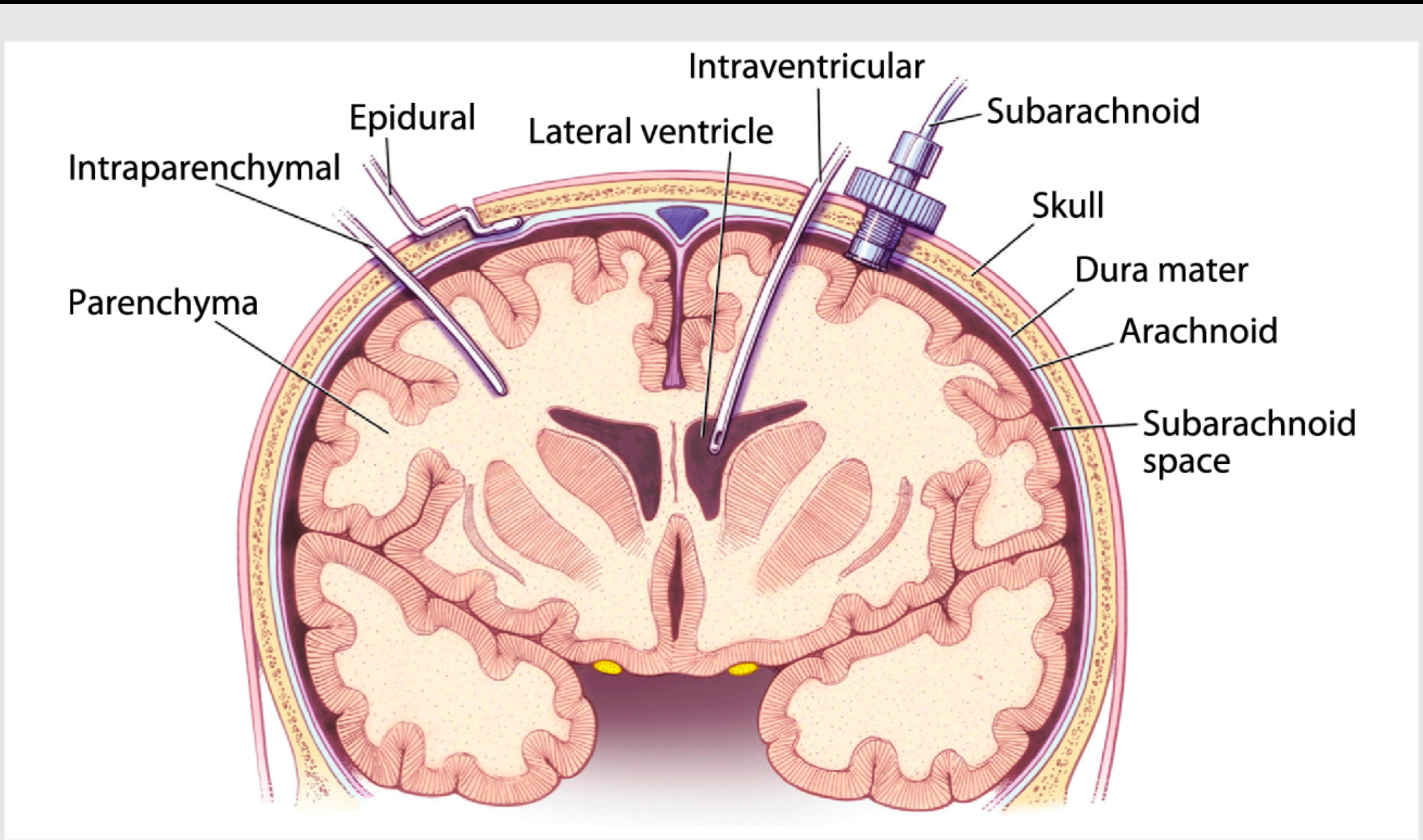
Fibreoptic ICP monitor

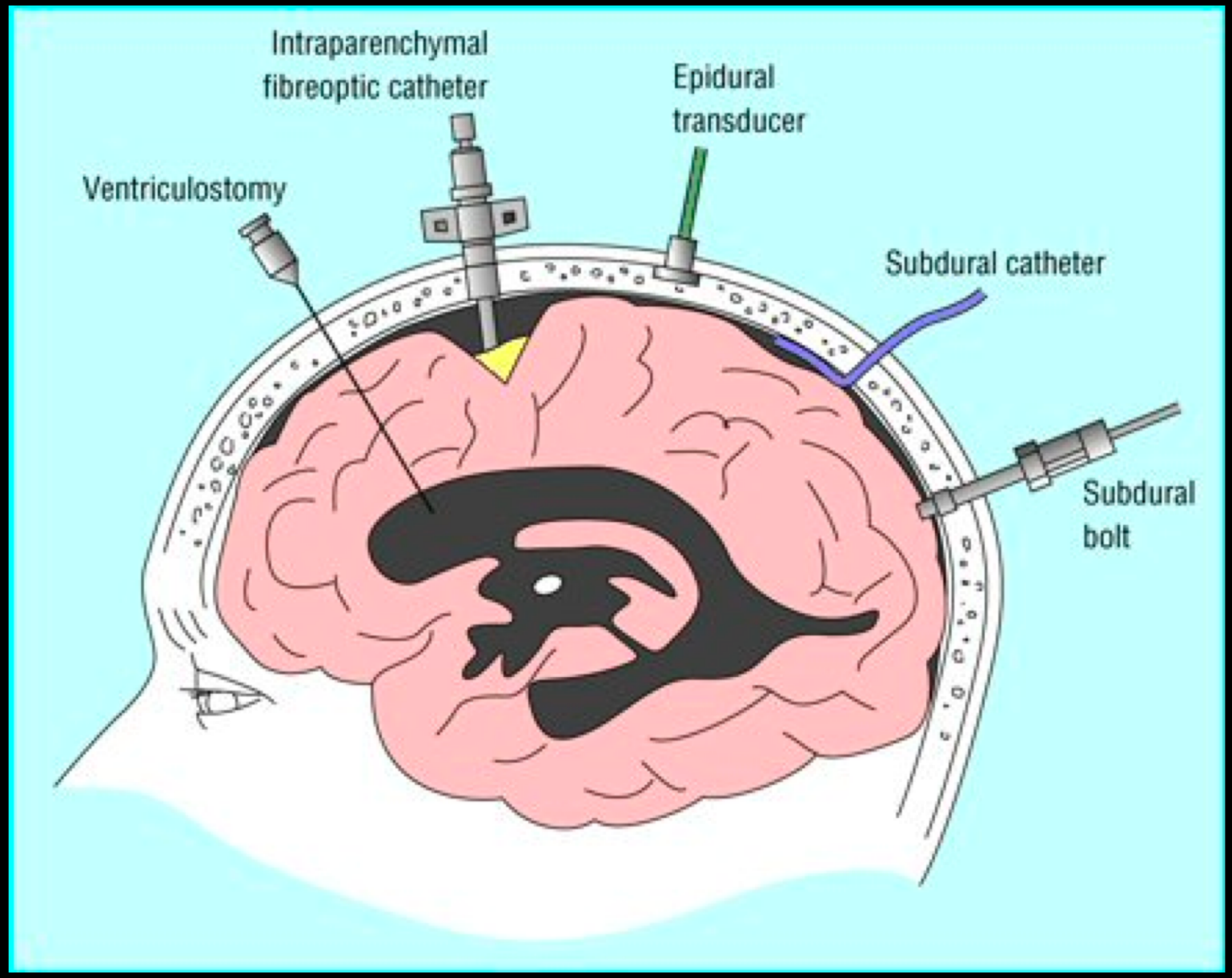
- Catheter tip measures the amount of light reflected off a pressure sensitive diaphragm
- Intraparenchymal Camino ICP monitor
  - Ease of insertion – Right frontal
  - Also in the region with pathology
  - Can be inserted in severely compressed ventricles or those with midline shift
  - Low risk of hemorrhage and infection
  - Zero drift: Recalibration cannot be performed
    - 2 mm Hg (first 24 hrs); 1 mm Hg (first 5 days) – Manufacturer
    - 0.5 – 3.2 mm Hg drift - Actual

Miniature Strain Gauge

- Codman MicroSensor ICP Transducer
  - Microchip pressure sensor at the tip of a flexible nylon cable that produces different electricity based on pressure
    - Intraventricular (Correlation coefficient 0.97 with EVD, Drift 0.2 mm Hg)
    - Intraparenchymal (Less accurate)
    - Subdural space (Not enough studies)

- Spiegelberg Parenchymal Transducer
  - Air pouch at the tip that is maintained at constant volume
  - Pressure transducer located in ICP monitor
  - Recalibration can be made easily
  - Good correlation with ICP measured by ventriculostomy


Intraventricular
Epidural
Lateral ventricle
Subarachnoid
Intraparenchymal
Skull
Dura mater
Parenchyma
Arachnoid
Subarachnoid space


Intraparenchymal
fibreoptic catheter
Epidural
transducer
Ventriculostomy
Subdural catheter
Subdural
bolt